

Mucool - Linac facility- Heat exchanger sizing

cd 09/28/01 Fermilab

Goal

This program permits us to determine the size of the HX to be used for the mucool linac cooling chamber.

Note- assumption:

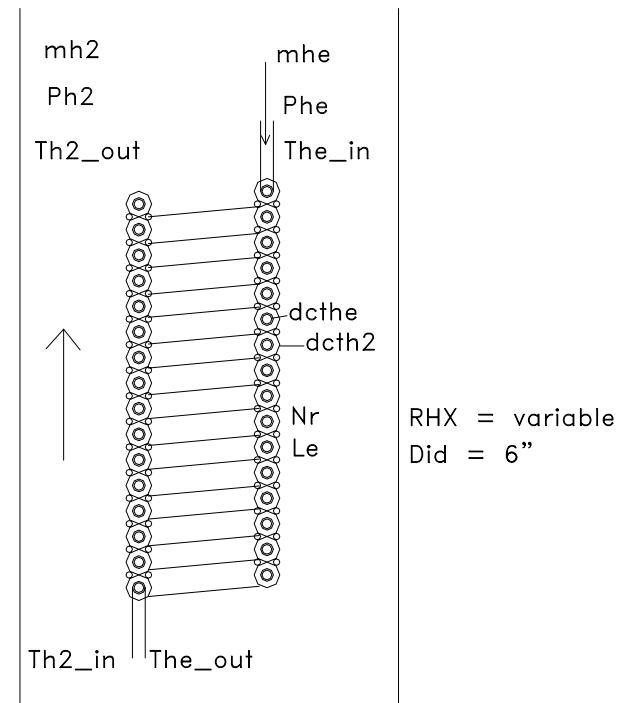
- Heat exchange: Helium/LH₂ co-current flow
- Number of iteration = 1000
- HX reduction diameter = 3 "

Parameters

- Power to extract from the absorber Q=500 W
- Temperature in/out He loop T_{hein}=14 K T_{heout}=16.7 K
- Temperature in/out H₂ loop T_{h2in}=18 K T_{h2out}=17 K
- Pressure He/H₂ P_{he}=0.135 MPa P_{h2}=0.121 MPa
- Mass-flow He/H₂ m_{he}=35 g/s m_{h2}=63 g/s
- Helium properties (Hepak)

Schematic

- Inner diam. cooling tube = 0.555 inch
- Thickness = 0.035 inch



Results

1- Surface of the heat exchange

Surface_{HX}=0.455 m²

2- Length for dct=5/8 inch

L_e=3.741 m

3- If DHX=4.5 inch and dct =5/8 inch than

N_r = 11 spires and L_{e2}=3.95 m

4- Pressure drop in HX2

drop= 8.4E-4 psi

5- Pressure drop in He

drop= 3.08 psi

6- Heat transfer coeff.

h= 0.302 W/cm²*K

Comments: Fine for 500 W to remove at 17 K, with DT=1K, But large DP_{he}

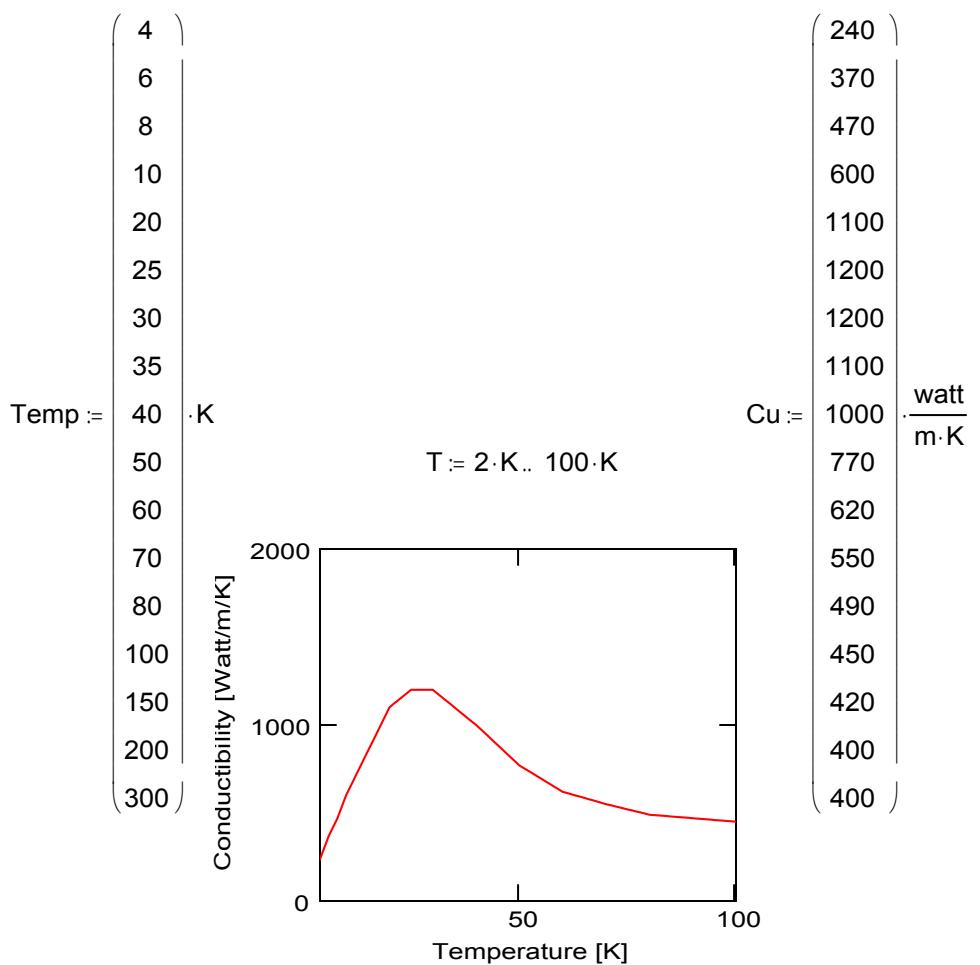
1. MATERIAL PROPERTIES

1.1.Thermal conductivity of copper

Data from file: CONDUC95.xls

Linear Interpolation

$$k_{Cu}(T) := \text{interp}(\text{Temp}, Cu, T)$$



1.2. Specific Heat of supercritical He at 1.35bar

Data from HEPAK

$$\text{Temp} := Y^{(1)} \cdot K$$

$$cp_{He} := Y^{(5)} \cdot \frac{\text{joule}}{\text{kg} \cdot \text{K}}$$

$$T := 4 \dots 100$$

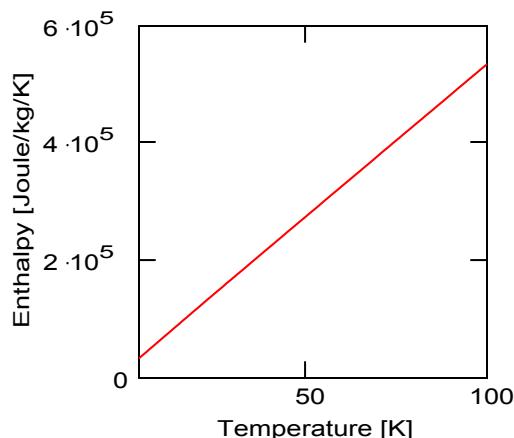
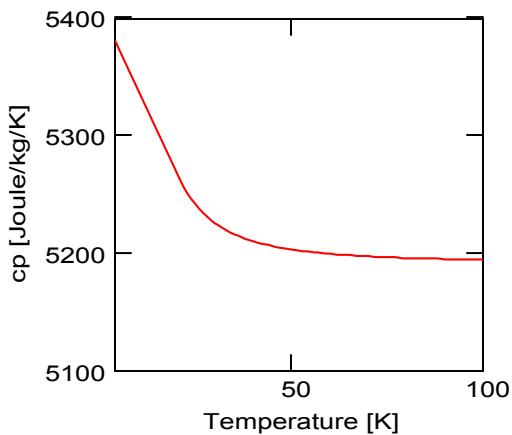
$$cp_{He}(T) := \text{interp}(\text{Temp}, cp_{He}, T)$$

$$Y := \text{READPRN}("He1_35bar.prn")$$

$$H_{He} := Y^{(6)} \cdot \frac{\text{joule}}{\text{kg}}$$

$$H_{He}(T) := \text{interp}(\text{Temp}, H_{He}, T)$$

$$cp_{He}(4 \cdot K) = 5.381 \times 10^3 \text{ kg}^{-1} \text{ K}^{-1} \text{ joule}$$



$T := 0 \text{..} 300 \text{K}$

density	viscosity	conductivity	specific heat	enthalphy
$\rho_{\text{He}} := Y^{(2)} \cdot \frac{\text{kg}}{\text{m}^3}$	$\mu_{\text{He}} := Y^{(3)} \cdot \text{Pa} \cdot \text{sec}$	$k_{\text{He}} := Y^{(4)} \cdot \frac{\text{watt}}{\text{m} \cdot \text{K}}$	$c_{\text{pHe}} := Y^{(5)} \cdot \frac{\text{joule}}{\text{kg} \cdot \text{K}}$	$H_{\text{He}} := Y^{(6)} \cdot \frac{\text{joule}}{\text{kg}}$
$\rho_{\text{He}}(T) := \text{interp}(\text{Temp}, \rho_{\text{He}}, T)$			$\rho_{\text{He}}(65 \text{K}) = 0.997 \text{ kg m}^{-3}$	
$\mu_{\text{He}}(T) := \text{interp}(\text{Temp}, \mu_{\text{He}}, T)$			$\mu_{\text{He}}(65 \text{K}) = 7.482 \times 10^{-6} \text{ kg m}^{-1} \text{ sec}^{-1}$	
$k_{\text{He}}(T) := \text{interp}(\text{Temp}, k_{\text{He}}, T)$			$k_{\text{He}}(65 \text{K}) = 0.055 \text{ m}^{-1} \text{ K}^{-1} \text{ watt}$	
$c_{\text{pHe}}(T) := \text{interp}(\text{Temp}, c_{\text{pHe}}, T)$			$c_{\text{pHe}}(65 \text{K}) = 5.199 \times 10^3 \text{ kg}^{-1} \text{ K}^{-1} \text{ joule}$	
$H_{\text{He}}(T) := \text{interp}(\text{Temp}, H_{\text{He}}, T)$			$H_{\text{He}}(19.477 \text{K}) = 1.156 \times 10^5 \text{ kg}^{-1} \text{ joule}$	

1.3. Specific Heat of supercritical Hydrogen at 1.21bar

Data from GASPAK

$Y_{\text{H2}} := \text{READPRN("H2_1bar21.prn")}$

$$\text{Temp} := Y_{\text{H2}}^{(1)} \cdot \text{K}$$

$$c_{\text{pH2}} := Y_{\text{H2}}^{(5)} \cdot \frac{\text{joule}}{\text{kg} \cdot \text{K}}$$

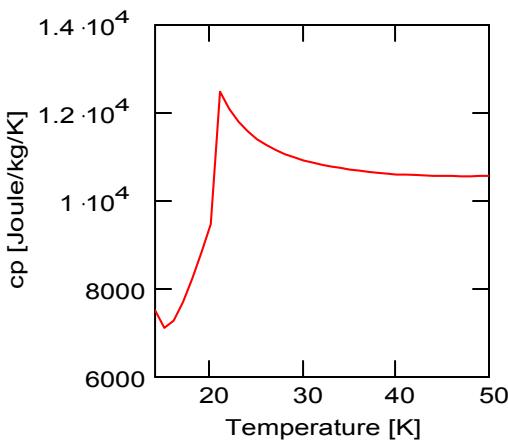
$$c_{\text{pH2}}(T) := \text{interp}(\text{Temp}, c_{\text{pH2}}, T)$$

$$c_{\text{pH2}}(14 \text{K}) = 7.516 \times 10^3 \text{ kg}^{-1} \text{ K}^{-1} \text{ joule}$$

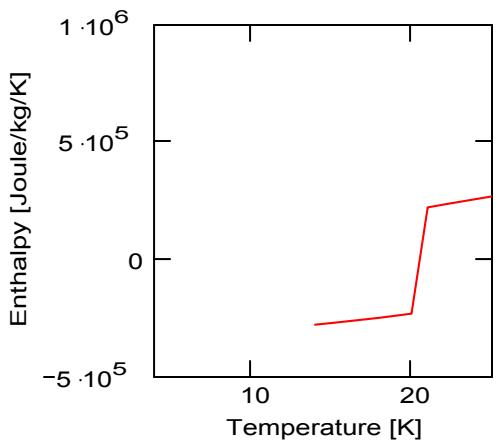
$$T := 14 \text{..} 50$$

$$H_{\text{H2}} := Y_{\text{H2}}^{(6)} \cdot \frac{\text{joule}}{\text{kg}}$$

$$H_{\text{H2}}(T) := \text{interp}(\text{Temp}, H_{\text{H2}}, T)$$



$$T := 0 \text{..} 300 \text{K}$$



density	viscosity	conductivity	specific heat	enthalphy
$\rho_{\text{H2}} := Y_{\text{H2}}^{(2)} \cdot \frac{\text{kg}}{\text{m}^3}$	$\mu_{\text{H2}} := Y_{\text{H2}}^{(3)} \cdot \text{Pa} \cdot \text{sec}$	$k_{\text{H2}} := Y_{\text{H2}}^{(4)} \cdot \frac{\text{watt}}{\text{m} \cdot \text{K}}$	$c_{\text{pH2}} := Y_{\text{H2}}^{(5)} \cdot \frac{\text{joule}}{\text{kg} \cdot \text{K}}$	$H_{\text{H2}} := Y_{\text{H2}}^{(6)} \cdot \frac{\text{joule}}{\text{kg}}$
$\rho_{\text{H2}}(T) := \text{interp}(\text{Temp}, \rho_{\text{H2}}, T)$			$\rho_{\text{H2}}(65 \text{K}) = 0.41 \text{ kg m}^{-3}$	
$\mu_{\text{H2}}(T) := \text{interp}(\text{Temp}, \mu_{\text{H2}}, T)$			$\mu_{\text{H2}}(65 \text{K}) = 3.054 \times 10^{-6} \text{ kg m}^{-1} \text{ sec}^{-1}$	
$k_{\text{H2}}(T) := \text{interp}(\text{Temp}, k_{\text{H2}}, T)$			$k_{\text{H2}}(65 \text{K}) = 0.047 \text{ kg m sec}^{-3} \text{ K}^{-1}$	
$c_{\text{pH2}}(T) := \text{interp}(\text{Temp}, c_{\text{pH2}}, T)$			$c_{\text{pH2}}(65 \text{K}) = 1.057 \times 10^4 \text{ m}^2 \text{ sec}^{-2} \text{ K}^{-1}$	
$H_{\text{H2}}(T) := \text{interp}(\text{Temp}, H_{\text{H2}}, T)$			$H_{\text{H2}}(65 \text{K}) = 6.973 \times 10^5 \text{ kg}^{-1} \text{ joule}$	

2. DATA - input

$$Q := 500 \cdot \text{watt}$$

$$i_{\max} := 1000$$

$$m_{dothe} := 35 \cdot 10^{-3} \cdot \frac{\text{kg}}{\text{sec}}$$

$$m_{dot2} := 63 \cdot 10^{-3} \cdot \frac{\text{kg}}{\text{sec}}$$

2.1. choose a set of temperatures:

$$T_{\text{hein}} := 14 \cdot \text{K}$$

$$T_{\text{h2in}} := 18 \cdot \text{K}$$

$$T_{\text{heout}} := 16.7 \cdot \text{K}$$

$$T_{\text{h2out}} := 17 \cdot \text{K}$$

2.2. Geometry

a) HX lenght - Solution 1

$$Nr := 11$$

Number of spires

$$DHX := 4.5 \cdot \text{in}$$

$$RHX := \frac{DHX}{2}$$

$$Le := 2 \cdot \pi \cdot RHX \cdot Nr \quad Le = 3.95 \text{m}$$

Solution 2

$$Nr_2 := 11$$

Number of spires

$$DHX_2 := 4.5 \cdot \text{in}$$

$$RHX_2 := \frac{DHX_2}{2}$$

$$Le_2 := 2 \cdot \pi \cdot RHX_2 \cdot Nr_2 \quad Le_2 = 3.95 \text{m}$$

b) Hx cooling spire

$$dcthe := .555 \cdot 25.4 \cdot \text{mm}$$

cooling tube inner diameter

$$dcthe = 14.097 \text{ mm}$$

$$thct := 0.035 \cdot 25.4 \cdot \text{mm}$$

wall thickness of cooling tube -

Any thickness would fit
if Q_c is very large..

$$thct = 0.889 \text{ mm}$$

$$dcth2 := dcthe + 2 \cdot thct$$

cooling tube outer diameter

$$dctheout := dcth2$$

c) HX - outer shell

$$Did := 6 \cdot \text{in}$$

$$Dred := 3 \cdot \text{in}$$

$$AH2 := 3.14 \cdot \frac{\left[\left(Did - 2 \cdot \frac{5 \cdot \text{in}}{8} \right)^2 - Dred^2 \right]}{4} \quad AH2 = 6.869 \times 10^{-3} \text{ m}^2$$

$$Per := 3.14 \cdot (Did + Dred)$$

$$DHXh := 4 \cdot \frac{AH2}{Per} \quad \text{Hydraulic diameter: } DHXh = 0.038 \text{ m}$$

$$LHX := 20 \cdot \text{in}$$

$$Acthe := \pi \cdot \left(\frac{dcthe}{2} \right)^2$$

cross-section area He

$$Acthe = 1.561 \times 10^{-4} \text{ m}^2$$

$$Ah2 := \left[\pi \cdot \left(\frac{DHXh}{2} \right)^2 \right]$$

cross-section area H2

$$Ah2 = 1.151 \times 10^{-3} \text{ m}^2$$

Determine the lenght of the HX for Nr spires

$$Scthe := \pi \cdot dcthe \cdot Le \quad \text{inner surface area cooling tube}$$

$$Lhx := Nr \cdot dcth2$$

$$Lhx = 6.875 \text{ in}$$

$$Scth2 := \pi \cdot dcth2 \cdot Le \quad \text{outer surface area cooling tube}$$

$$Scthe = 0.175 \text{ m}^2$$

$$Scth2 = 0.197 \text{ m}^2$$

3. COOLING SCHEME:

3.1. Forced convection heat transfer coefficients (turbulent flow)

$$\text{Pr}(\mu, \text{cp}, k, T) := \mu(T) \cdot \frac{\text{cp}(T)}{k(T)}$$

Prandtl number

$$\text{Re}(\rho, v, d, \mu, T) := \rho(T) \cdot v \cdot \frac{d}{\mu(T)}$$

Reynolds number

$$\text{Nuh2}(\text{Re}) := 0.083 \cdot \text{Re}^{0.85}$$

Nusselt number - hydrogen - shell side

$$\text{Nu}(\text{Re}, \text{Pr}) := 0.023 \cdot \text{Re}^{0.8} \cdot \text{Pr}^{0.4}$$

Nusselt number - helium -inner side

$$h(\text{Nu}, k, T, d) := \text{Nu} \cdot \frac{k(T)}{d}$$

convection heat transfer coefficient
for natural convection in monophasic He

3.2. Helium flow velocities

$$mdothe = 0.035 \text{ kg sec}^{-1}$$

He mass flow rate

$$vHe_i := \frac{mdothe}{A_{\text{the}} \cdot \rho_{\text{He}}(The_i)}$$

vHe_i

$$Prhe_i := \text{Pr}(\mu_{\text{He}}, \text{cp}_{\text{He}}, k_{\text{He}}, The_i)$$

Prhe

$$Rehe_i := \text{Re}(\rho_{\text{He}}, v_{\text{He}_i}, dc_{\text{the}}, \mu_{\text{He}}, The_i)$$

Rehe

$$Nuhe_i := \text{Nu}(Rehe_i, Prhe_i)$$

Nuhe

$$hc_{\text{the}_i} := h(Nuhe_i, k_{\text{He}}, The_i, dc_{\text{the}})$$

hc_{the}

$$The_i := The_{\text{in}} + i \cdot \frac{(The_{\text{out}} - The_{\text{in}})}{imax}$$

$$mdothe = 0.035 \text{ kg sec}^{-1}$$

$$A_{\text{the}} = 1.561 \times 10^{-4} \text{ m}^2$$

$$Prhe_{1000} = 0.722$$

$$Rehe_{1000} = 9.795 \times 10^5$$

$$A_{\text{the}} = 1.561 \times 10^{-4} \text{ m}^2$$

$$The_{1000} = 16.7 \text{ K}$$

$$dc_{\text{the}} = 0.014 \text{ m}$$

$$vHe_{1000} = 59.943 \text{ m sec}^{-1}$$

3.3. Hydrogen flow velocities

$$mdoth2 = 0.063 \text{ kg sec}^{-1}$$

Hydrogen mass flow rate

$$vh2(m, A, \rho, T) := \frac{m}{A \cdot \rho(T)}$$

$$vH2_i := vh2(mdoth2, Ah2, \rho_{\text{H2}}, Th2_i)$$

vH2

$$Prh2_i := \text{Pr}(\mu_{\text{H2}}, \text{cp}_{\text{H2}}, k_{\text{H2}}, Th2_i)$$

Prh2

$$Reh2_i := \text{Re}(\rho_{\text{H2}}, vH2_i, dc_{\text{th2}}, \mu_{\text{H2}}, Th2_i)$$

Reh2

$$Nuh2_i := Nuh2(Reh2_i)$$

Nuh2

$$hc_{\text{th2}_i} := h(Nuh2_i, k_{\text{H2}}, Th2_i, dc_{\text{th2}})$$

hc_{th2}

$$Th2_i := Th2_{\text{out}} - \left[i \cdot \frac{(Th2_{\text{out}} - Th2_{\text{in}})}{imax} \right]$$

$$mdoth2 = 0.063 \text{ kg sec}^{-1}$$

$$Ah2 = 1.151 \times 10^{-3} \text{ m}^2$$

$$Reh2_{1000} = 5.195 \times 10^4$$

3.4. Calculation of the wall temperature

$$T_{cti} := \frac{[(The_i \cdot hcthe_i) + (Th2_i \cdot hcth2_i)]}{(hcthe_i + hcth2_i)}$$

The_i Th2_i Tct_i

3.5. Convection in helium

$$Scthe_i := \frac{\frac{Q}{imax}}{hcthe_i \cdot (Tct_i - The_i)}$$

Scthe_i

3.6. Convection in hydrogen

$$Scth2_i := \frac{\frac{Q}{imax}}{(-hcth2)_i \cdot (Tct_i - Th2_i)}$$

Scth2_i

3.7. Calculation of the HX surface and lenght

$$\text{SurfaceHX} := \sum_i Scth2_i$$

$$dcthe = 0.014 \text{ m}$$

$$L(d) := \frac{\text{SurfaceHX}}{\pi \cdot d}$$

Surface of exchange

$$\text{SurfaceHX} = 0.16568 \text{ m}^2$$

Lenght of HX for dcthe

$$L(dcthe) = 3.74099 \text{ m}$$

4. Approach with the flux balance

4.1. Solid conduction

$$thct = 8.89 \times 10^{-4} \text{ m}$$

$$Le = 3.95 \text{ m}$$

$$Scthe := \pi \cdot dcthe \cdot Le$$

$$Scthe = 0.175 \text{ m}^2$$

$$Scth2 := \pi \cdot dcth2 \cdot Le$$

$$Scth2 = 0.197 \text{ m}^2$$

$$Tcthe := 16.5 \text{ K}$$

$$Tcth2 := 17.95 \text{ K}$$

used for Qs calculation

$$Le2 = 3.95 \text{ m}$$

$$The := \frac{Thein + Theout}{2}$$

$$The = 15.35 \text{ K}$$

$$Th2 := \frac{Th2in + Th2out}{2}$$

$$Th2 = 17.5 \text{ K}$$

heat conduction path though the wall thickness

$$Qs(Tcth2) = 6.944 \times 10^4 \text{ m}^{-1} \text{ watt}$$

$$Qs(Tcth2) := \frac{Scthe}{thct \cdot Le2} \cdot \int_{Tcthe}^{Tcth2} kCu(T) dT$$

4.2. Power to extract from the hydrogen

$$Ptot := \frac{Q}{Le2}$$

$$Ptot = 126.585 \text{ m}^{-1} \text{ watt}$$

4.3. Helium Cooling Capacity

$$pHe(mdothe, Theout, Thein) := \frac{[mdothe \cdot cpHe(The) \cdot (Theout - Thein)]}{Le2}$$

nHe(mdothe, Theout, Thein) = 126.849 m⁻¹ watt

4.4. Hydrogen Cooling Capacity

$$\rho H_2(mdoth2, Th2out, Th2in) := \frac{-[mdoth2 \cdot (HH2(Th2out) - HH2(Th2in))]}{Le2}$$

$$\rho H_2(mdoth2, Th2out, Th2in) = 127.597 \text{ m}^{-1} \text{ watt}$$

4.5. Convection in helium

$$\rho He := \rho He(Tcthe) \quad \rho He = 3.771 \text{ kg m}^{-3} \quad dchthe = 0.014 \text{ m}$$

$$\mu He := \mu He(Tcthe) \quad \mu He = 3.205 \times 10^{-6} \text{ sec}^2 \text{ m}^{-3} \text{ watt} \quad Tcthe = 16.5 \text{ K}$$

$$vHe := \frac{mdothe}{Acthe \cdot \rho He} \quad vHe = 59.466 \text{ m sec}^{-1}$$

$$cpHe := cpHe(Tcthe) \quad cpHe = 5.294 \times 10^3 \text{ m}^2 \text{ sec}^{-2} \text{ K}^{-1}$$

$$kHe := kHe(Tcthe) \quad kHe = 0.023 \text{ kg m sec}^{-3} \text{ K}^{-1}$$

$$Rehe(\rho, v, d, \mu) := \rho \cdot v \cdot \frac{d}{\mu} \quad Rehe := Rehe(\rho He, vHe, dchthe, \mu He) \quad Rehe = 9.863 \times 10^5$$

$$Prhe(\mu, cp, k) := \mu \cdot \frac{cp}{k} \quad Prhe := Prhe(\mu He, cpHe, kHe) \quad Prhe = 0.722$$

$$Nu(Re, Pr) := 0.023 \cdot Re^{0.8} \cdot Pr^{0.4} \quad Nuhe := Nu(Rehe, Prhe) \quad Nuhe = 1.26 \times 10^3$$

$$h(Nu, k, d) := Nu \cdot \frac{k}{d} \quad hcthe := h(Nuhe, kHe, dchthe) \quad hcthe = 2.101 \times 10^3 \text{ m}^{-2} \text{ K}^{-1} \text{ watt}$$

$$Qc(The, Tcthe) := \frac{Scthe \cdot hcthe \cdot (Tcthe - The)}{Le2} \quad Qc(The, Tcthe) = 107.002 \text{ m}^{-1} \text{ watt}$$

$$Tcthe = 16.5 \text{ K}$$

4.6. Convection in hydrogen

$$\rho H_2 := \rho H_2(Tcth2) \quad \rho H_2 = 73.35 \text{ kg m}^{-3} \quad dchth2 = 0.016 \text{ m}$$

$$\mu H_2 := \mu H_2(Tcth2) \quad \mu H_2 = 1.765 \times 10^{-5} \text{ sec}^2 \text{ m}^{-3} \text{ watt} \quad Tcth2 = 17.95 \text{ K}$$

$$vH_2 := \frac{mdoth2}{Ah2 \cdot \rho H_2} \quad vH_2 = 0.746 \text{ m sec}^{-1}$$

$$cpH_2 := cpH_2(Tcth2) \quad cpH_2 = 8.204 \times 10^3 \text{ m}^2 \text{ sec}^{-2} \text{ K}^{-1}$$

$$kH_2 := kH_2(Tcth2) \quad kH_2 = 0.101 \text{ kg m sec}^{-3} \text{ K}^{-1}$$

$$Reh2(\rho, v, d, \mu) := \rho \cdot v \cdot \frac{d}{\mu} \quad Reh2 := Reh2(\rho H_2, vH_2, dchth2, \mu H_2) \quad Reh2 = 5.172 \times 10^4$$

$$Prh2(\mu, cp, k) := \mu \cdot \frac{cp}{k} \quad Prh2 := Prh2(\mu H_2, cpH_2, kH_2) \quad Prh2 = 1.366$$

$$Nuh2(Re) := 0.083 \cdot Re^{0.85} \quad Nuh2 := Nuh2(Reh2) \quad Nuh2 = 842.695$$

$$h(Nu, k, d) := Nu \cdot \frac{k}{d} \quad hcthe := h(Nuh2, kH_2, dchth2) \quad hcthe = 5.359 \times 10^3 \text{ m}^{-2} \text{ K}^{-1} \text{ watt}$$

$$Qch2(Th2, Tcth2) := \frac{Scth2 \cdot hcthe \cdot (Tcth2 - Th2)}{Le2} \quad Qch2(Th2, Tcth2) = 120.26 \text{ m}^{-1} \text{ watt}$$

$$Tcth2 = 17.95 \text{ K}$$

4.7. Pressure drop

In helium circuit

$$Re_{He} = 9.863 \times 10^5$$

$$f := 0.003$$

$$f_{He} := 0.00332 + \frac{0.221}{Re_{He}^{0.237}}$$

turbulent
 $d_{cHe} = 0.014 \text{ m}$
 $\rho_{He} = 3.771 \text{ kg m}^{-3}$
 $v_{He} = 59.466 \text{ m sec}^{-1}$

$$drop := f_{He} \cdot \frac{Le \cdot \rho_{He} \cdot v_{He}^2}{d_{cHe} \cdot 2}$$

$Le_2 = 3.95 \text{ m}$
 $DHx_h = 0.038 \text{ m}$

$$f_{He} = 0.012$$

$$drop = 2.188 \times 10^4 \text{ Pa} \quad drop = 3.173 \text{ psi}$$

$$drop2 := f_{He} \cdot \frac{Le_2 \cdot \rho_{He} \cdot v_{He}^2}{d_{cHe} \cdot 2}$$

$$drop2 = 2.188 \times 10^4 \text{ Pa} \quad drop2 = 3.173 \text{ psi}$$

In Hydrogen circuit

$$Re_{H2} = 5.172 \times 10^4$$

$$f_{H2} := \frac{1}{(1.8 \cdot \log(Re_{H2}) - 1.64)^2}$$

Blasius equation $Re < 10^5$

$$f_{H2} = 0.021$$

$$drop_{H2} := f_{H2} \cdot \frac{LHX \cdot \rho_{H2} \cdot v_{H2}^2}{DHx_h \cdot 2}$$

$\rho_{H2} = 73.35 \text{ kg m}^{-3}$
 $v_{H2} = 0.746 \text{ m sec}^{-1}$

$$drop_{H2} = 5.789 \text{ Pa} \quad drop_{H2} = 8.396 \times 10^{-4} \text{ p}$$

$LHX = 0.508 \text{ m}$
 $DHx_h = 0.038 \text{ m}$

4.8. RESULTS

$$Q_c(The, T_{cHe}) = 107.002 \text{ m}^{-1} \text{ watt}$$

$$Q = 500 \text{ watt}$$

$$P_{tot} = 126.585 \text{ m}^{-1} \text{ watt}$$

The Q_s is larger than Q_i - any thickness of the copper cooling tube would fit - this parameter is not a limitation

$$Q_s(T_{cHe}) = 6.944 \times 10^4 \text{ m}^{-1} \text{ watt}$$

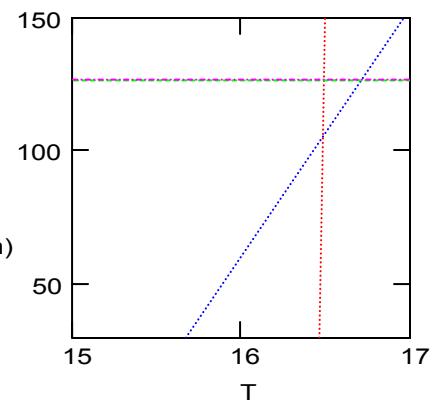
$$Q_{ch2}(Th2, T_{cHe}) = 120.26 \text{ m}^{-1} \text{ watt}$$

$$\rho_{He}(mdothe, Theout, Thein) = 126.849 \text{ m}^{-1} \text{ watt}$$

$$\rho_{H2}(mdoth2, Th2out, Th2in) = 127.597 \text{ m}^{-1} \text{ watt}$$

$$T := 4 \cdot K.. 200 \cdot K$$

Legend:
+---+ $Q_s(T)$
----- $Q_c(The, T)$
---- P_{tot}
---- $\rho_{He}(mdothe, Theout, Thein)$



SUMMARY

$$Q = 500 \text{ watt}$$

$$P_{\text{tot}} = 126.585 \text{ m}^{-1} \text{ watt}$$

$$\text{SurfaceHX} = 0.16568 \text{ m}^2$$

$$L(\text{dcthe}) = 3.741 \text{ m}$$

Helium

$$T_{\text{hein}} = 14 \text{ K}$$

$$T_{\text{he}} = 15.35 \text{ K}$$

$$S_{\text{cthe}} = 0.175 \text{ m}^2$$

$$m_{\text{dothe}} = 0.035 \text{ kg sec}^{-1}$$

$$T_{\text{heout}} = 16.7 \text{ K}$$

$$m_{\text{dothe}} = 0.035 \text{ kg sec}^{-1}$$

$$\text{drop} = 2.188 \times 10^4 \text{ Pa}$$

$$\text{drop} = 3.173 \text{ psi}$$

$$\text{drop2} = 2.188 \times 10^4 \text{ Pa}$$

$$\text{drop2} = 3.173 \text{ psi}$$

Hydrogen

$$T_{\text{H2in}} = 18 \text{ K}$$

$$T_{\text{H2}} = 17.5 \text{ K}$$

$$S_{\text{cth2}} = 0.197 \text{ m}^2$$

$$m_{\text{dot2}} = 0.063 \text{ kg sec}^{-1}$$

$$T_{\text{H2out}} = 17 \text{ K}$$

$$\text{drop}_{\text{H2}} = 5.789 \text{ Pa}$$

$$\text{drop}_{\text{H2}} = 8.396 \times 10^{-4} \text{ psi}$$

$$m_{\text{dot2}} = 0.063 \text{ kg sec}^{-1}$$

Proposal for the HX design, Nr number of spire, RHX, radius

$$DHX = 4.5 \text{ in}$$

$$Nr = 11$$

$$RHX = 0.057 \text{ m}$$

$$Le = 3.95 \text{ m}$$

$$\text{drop} = 3.173 \text{ psi}$$

$$DHX2 = 4.5 \text{ in}$$

$$Nr2 = 11$$

$$RHX2 = 0.057 \text{ m}$$

$$Le2 = 3.95 \text{ m}$$

$$\text{drop2} = 3.173 \text{ psi}$$

$$i_{\text{max}} = 1 \times 10^3$$

Compare to: $L(\text{dcthe}) = 3.741 \text{ m}$

$$dcthe = 14.097 \text{ mm}$$

$$dctheout = 0.016 \text{ m}$$

$$thct = 8.89 \times 10^{-4} \text{ m}$$

Heat transfer coefficient

$$h := \frac{Q}{\text{SurfaceHX} \cdot (T_{\text{H2in}} - T_{\text{H2out}})}$$

$$h = 0.302 \text{ K}^{-1} \frac{\text{watt}}{\text{cm}^2}$$

$$(T_{\text{H2in}} - T_{\text{H2out}}) = 1 \text{ K}$$

$$\text{SurfaceHX} = 0.166 \text{ m}^2$$

$$Q = 500 \text{ watt}$$

